Natural Gas as a Bridge to a Renewable Energy Future

Presented by:

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at

Natural Gas/Renewable Energy Hybrids Workshop

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Natural Gas-Renewable Energy Alliance

▪American Bioenergy Association	▪Geothermal Energy Association
▪American Gas Association	▪Interstate Natural Gas Association of America
▪American Wind Energy Association	▪Kyocera Solar
▪BP Amoco	▪National BioEnergy Industries Association
▪Coalition for Gas-Based Environmental Solutions	▪Plug Power
▪Columbia Energy Group	▪Solar Energy Industries Association
▪Distributed Power Coalition of America	▪Solar Turbines, Inc.
▪Future Energy Resources Corporation (FERCO)	▪Sempra Energy
▪Gas Technology Institute	▪Spire Corporation

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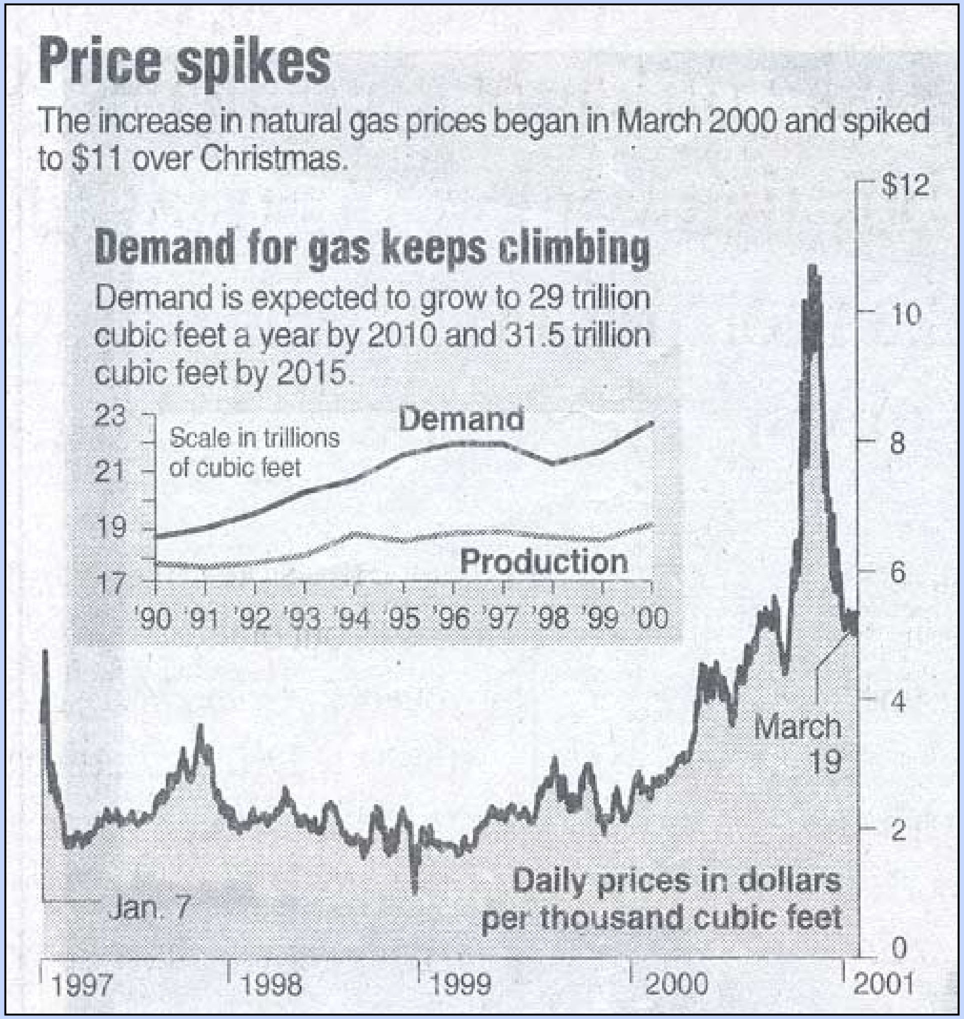
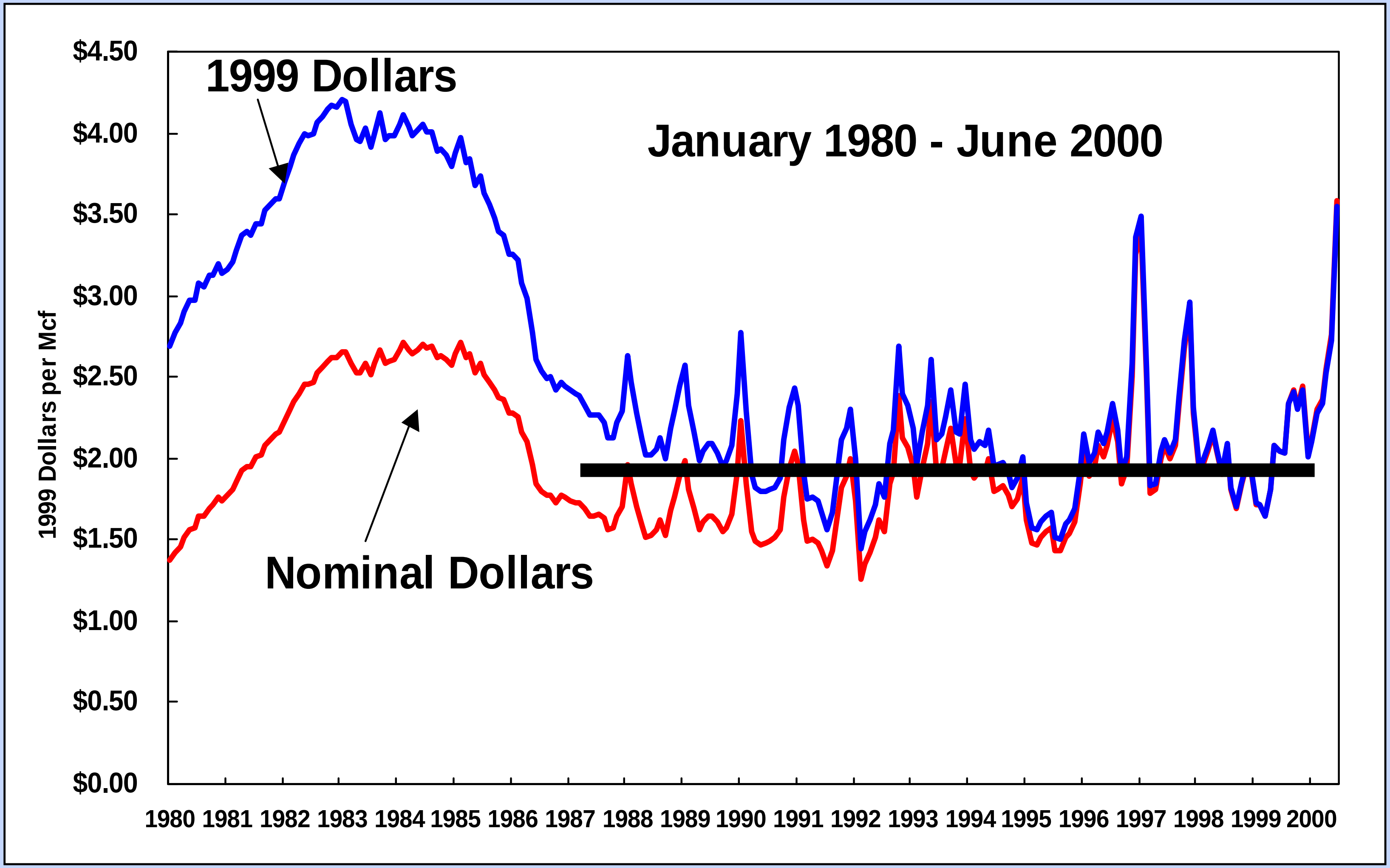
The Denver Post
“Natural Gas Falls from its Pedestal”



Article from Denver Post: March 25, 2001

U.S. Wellhead Gas Prices - Have Averaged $2.00/mcf For 15 Years (Despite Ups and Downs)



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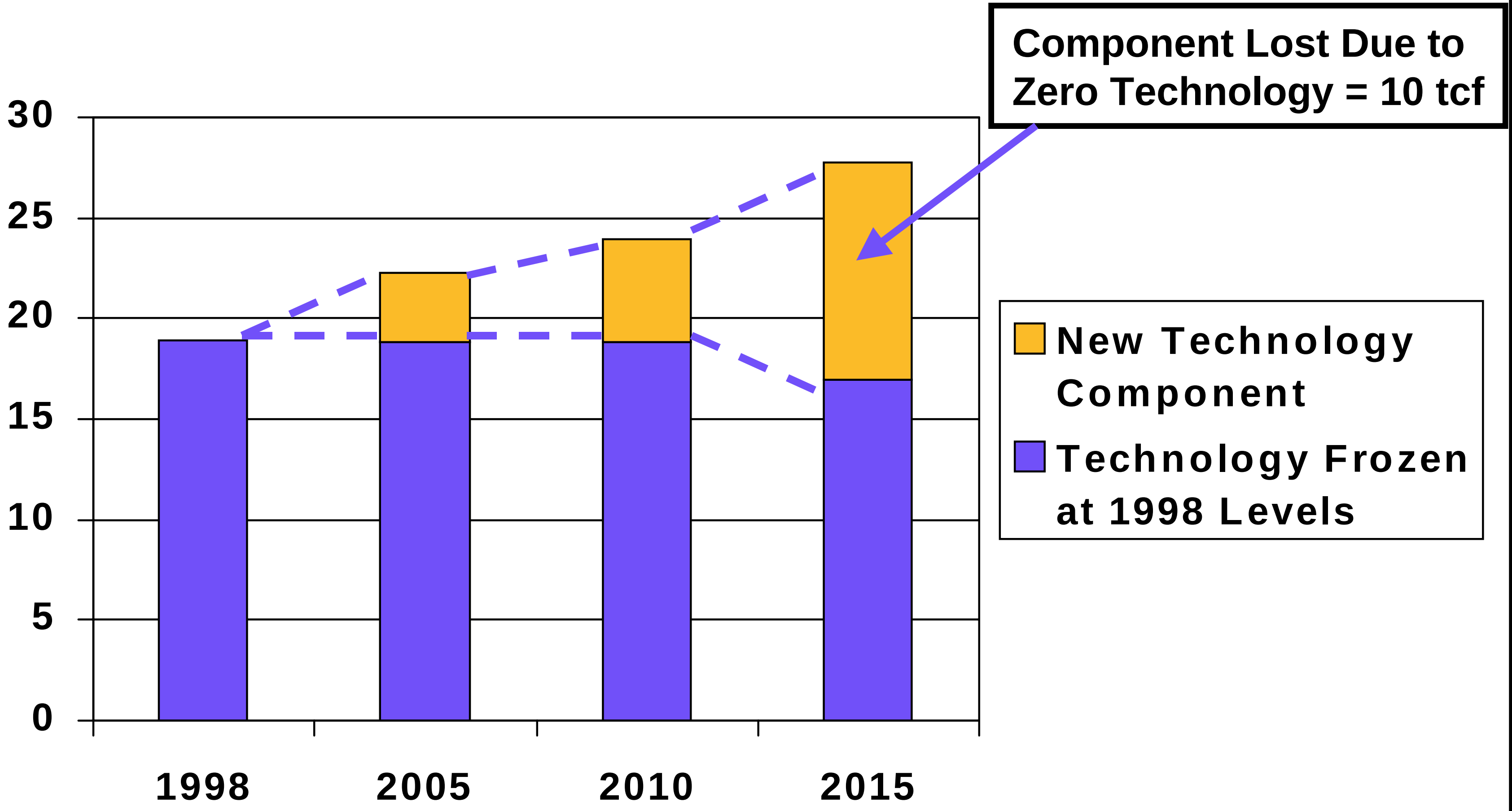
Technology Effects on U.S. Lower-48 Gas Production (tcf)



Approaches to Increasing U.S. Gas Supply

- **LNG Infrastructure**
- **Conventional Gas**
  - Exploration
  - Infield Reserve Growth
  - Enhanced Recovery
- **Deepwater Offshore**
- **Artic**
- **Deep Onshore Gas**
- **Tight Gas**
- **Coalbed Methane**
- **Shale Gas**
- **Substitute Natural Gas (Coal, Biomass, etc.)**
- **Gas Hydrates**

Peak-Load Generation & Gas Supply Simple-Cycle Combustion Turbine

- Assume: 15% capital recovery, \$350/kW capital cost, \$4/MBTU fuel price, 10,000 Btu/kWh heat rate, .5 cents/kWh O&M
- Profitable at 955 hrs/year peaking operation for electricity sales at \$100/MWh
- At \$1000/MWh electricity price, only 55 hrs/year required to be profitable

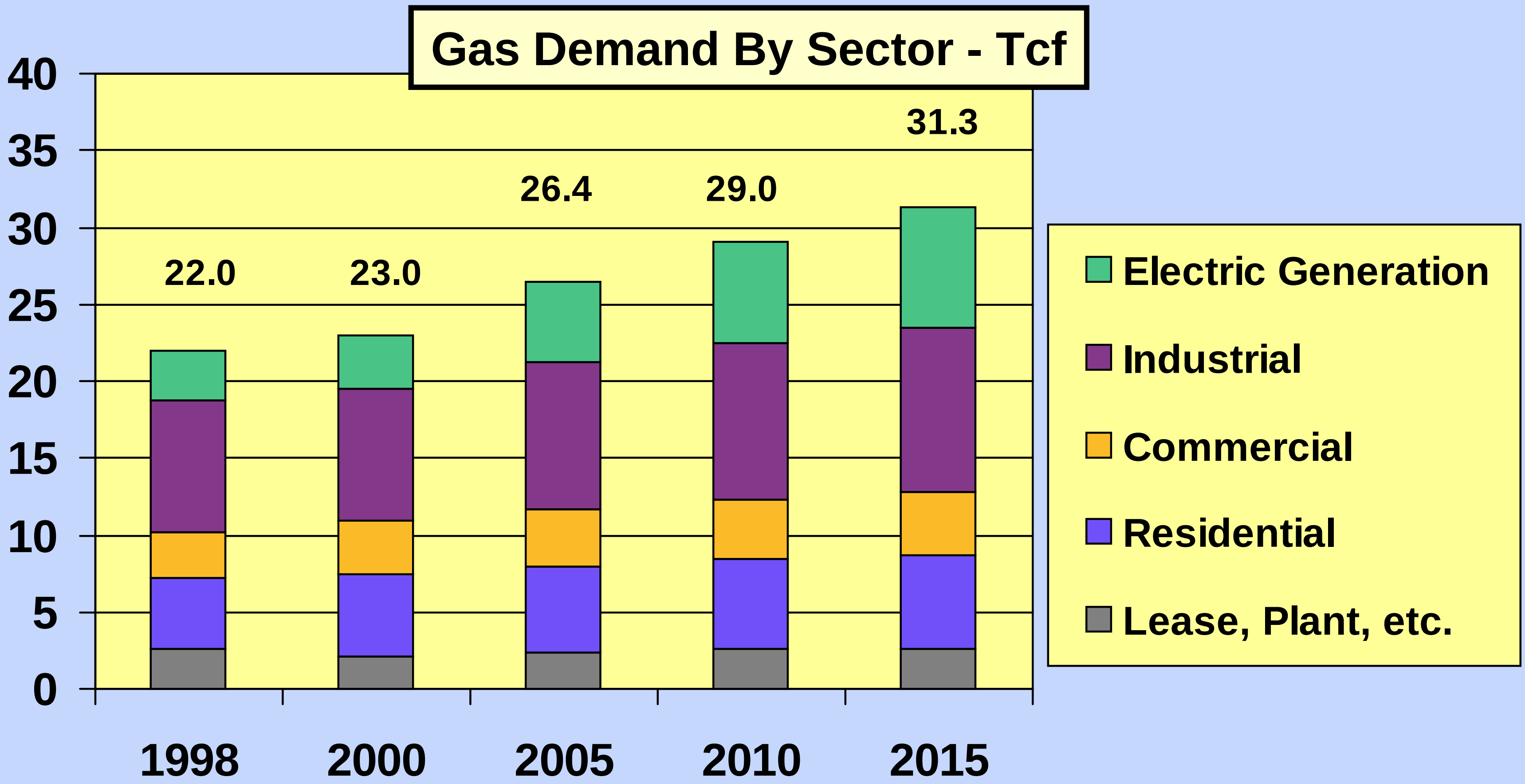
Natural Gas Combined-Cycle Baseload Power Generation Economics

- **Assume: 15% capital recovery, $500/kW capital cost, $4/MBTU fuel price, 6,700 Btu/kWh heat rate (LHV - 57% efficiency), .5 cents/kWh O&M**
- **At 85% annual operating factor, power cost is 4.2 cents/kWh**
- **Very short lead time for construction and minimal regulatory risk compared to coal or nuclear power plants**

World Natural Gas Utilization

- Large growth in use due to substantial supply base and improving delivery options: super pipelines, LNG, gas-to-liquids
- Over 5000 Quads of known reserves – half is “stranded gas”
- 16 Quads per year currently being flared or re-injected – if recovered or converted to synthetic Diesel would be ~10% of current world oil use

U.S. Gas Demand Projection Through 2015



(1999 NPC Reference Case)

Natural Gas – Renewable Energy Hybrids

- Industrial End-use represents ~42% of US Natural Gas Consumption
- Bioenergy (heat, fuelgas, or oil) could substitute for natural gas in most industrial applications

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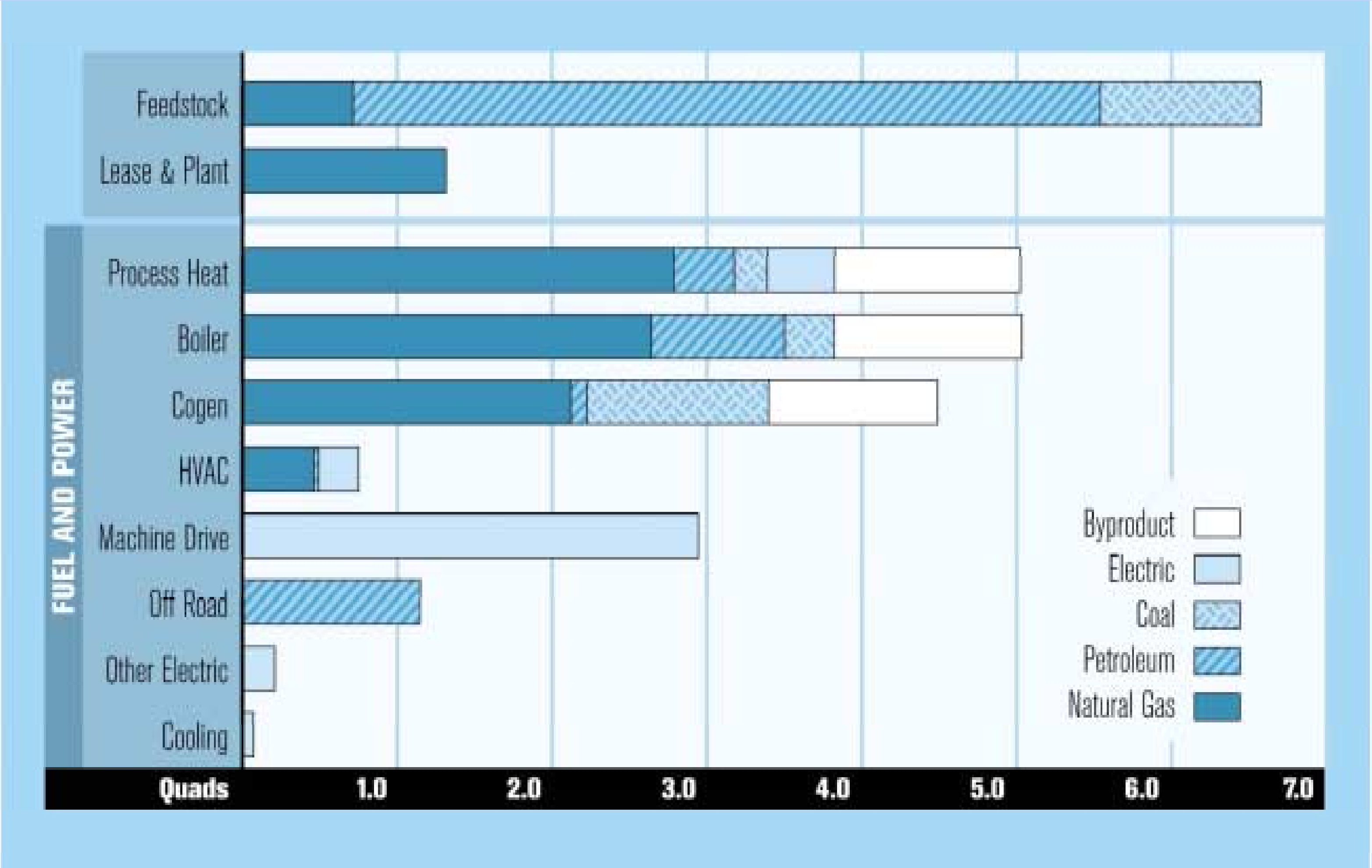
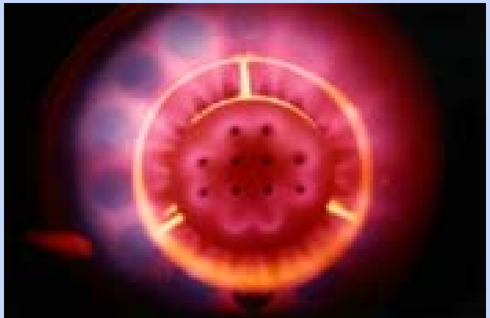
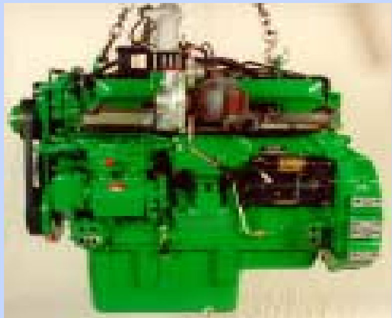
Industrial End Uses by Fuel Type (1995)



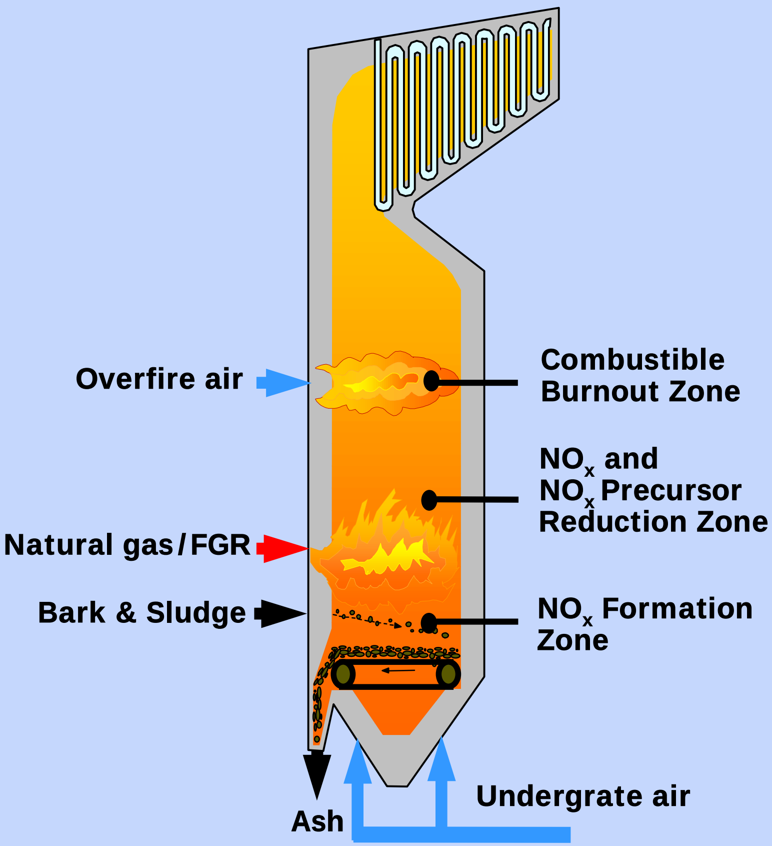
Applications for Co-utilization of Natural Gas and Biomass

- Co-firing Natural Gas and Biomass in (Stoker) Boilers
- Co-firing (or Direct Combustion) of Biomass LCV Gas in Energy Conversion Devices (Burners, Engines and Gas Turbines)
- Biomass Gasification Followed by Co-firing of Fuel Gas and Natural Gas in Energy Conversion Devices (Burners, Engines, and Gas Turbines)
- Pyrolysis of Biomass Followed by Co-firing Liquid Fuels and Natural Gas - (Burners, Engines, and Turbine Engines)





GTI METHANE de-NOX® Reburning Process for Stoker Boilers



A reburn technology using 5% to 25% natural gas heat input for combustion improvement and 50-70% NO_x reduction in coal-, biomass-, and MSW-fired stoker boilers

Natural Gas – Renewable Energy Hybrids

- Electrical Generation is the Most Rapidly Growing Market for Natural Gas
- Wind and Photovoltaics could be Combined with Natural Gas to Firm Up the Intermittent Nature of Renewable Power Plants
- Longer-term Renewables can Provide Most of the Hydrogen to power Fuel Cells

Wind Turbine Cost-of-Energy Trends

1979: 40 cents/kWh

2000:
4 - 6 cents/kWh

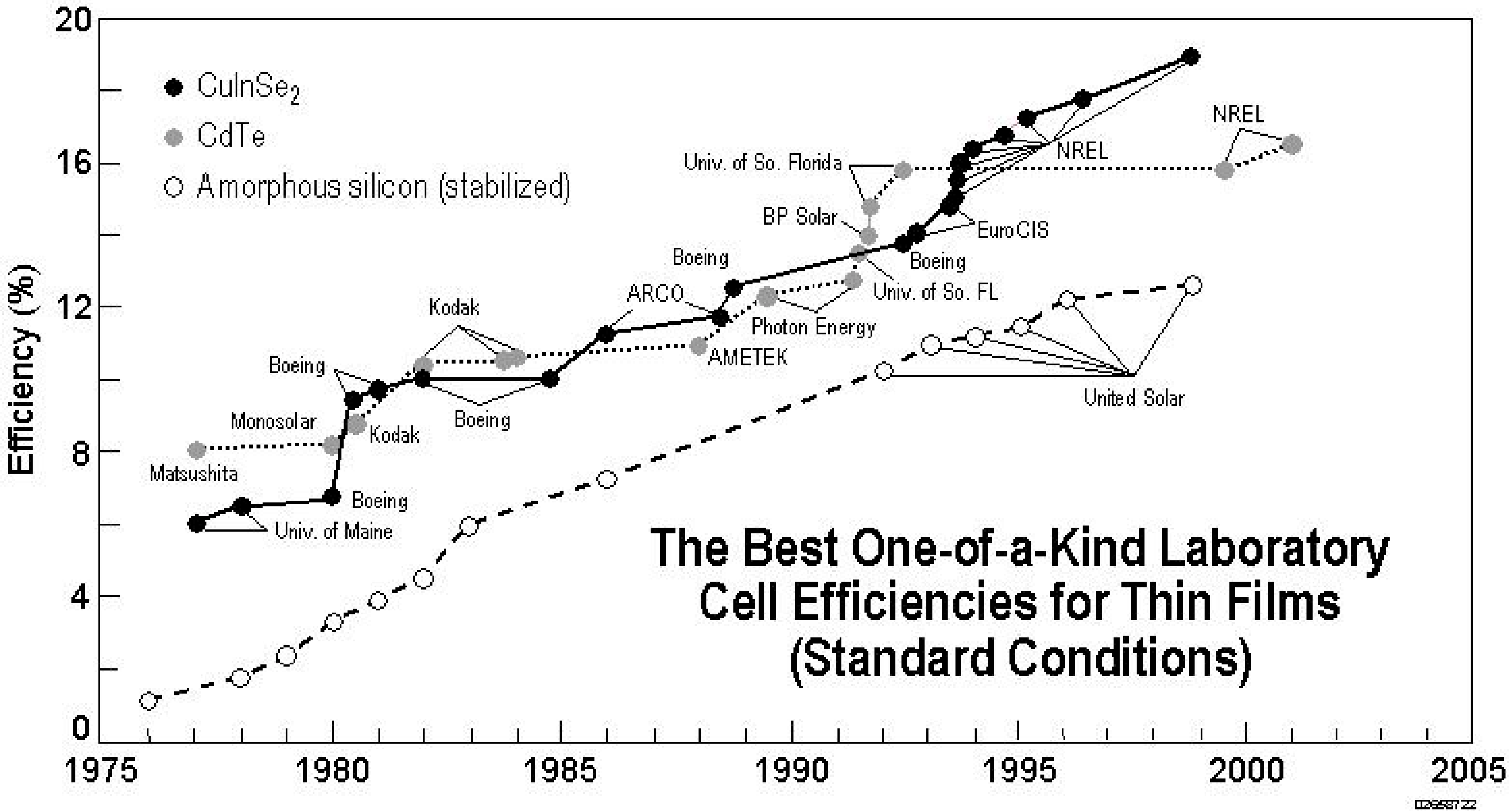
NSP 107 MW Lake Benton wind farm
4 cents/kWh (unsubsidized)

- Increased Turbine Size
- R&D Advances
- Manufacturing Improvements

2004:
3 - 5 cents/kWh

Bob Thresher - NREL

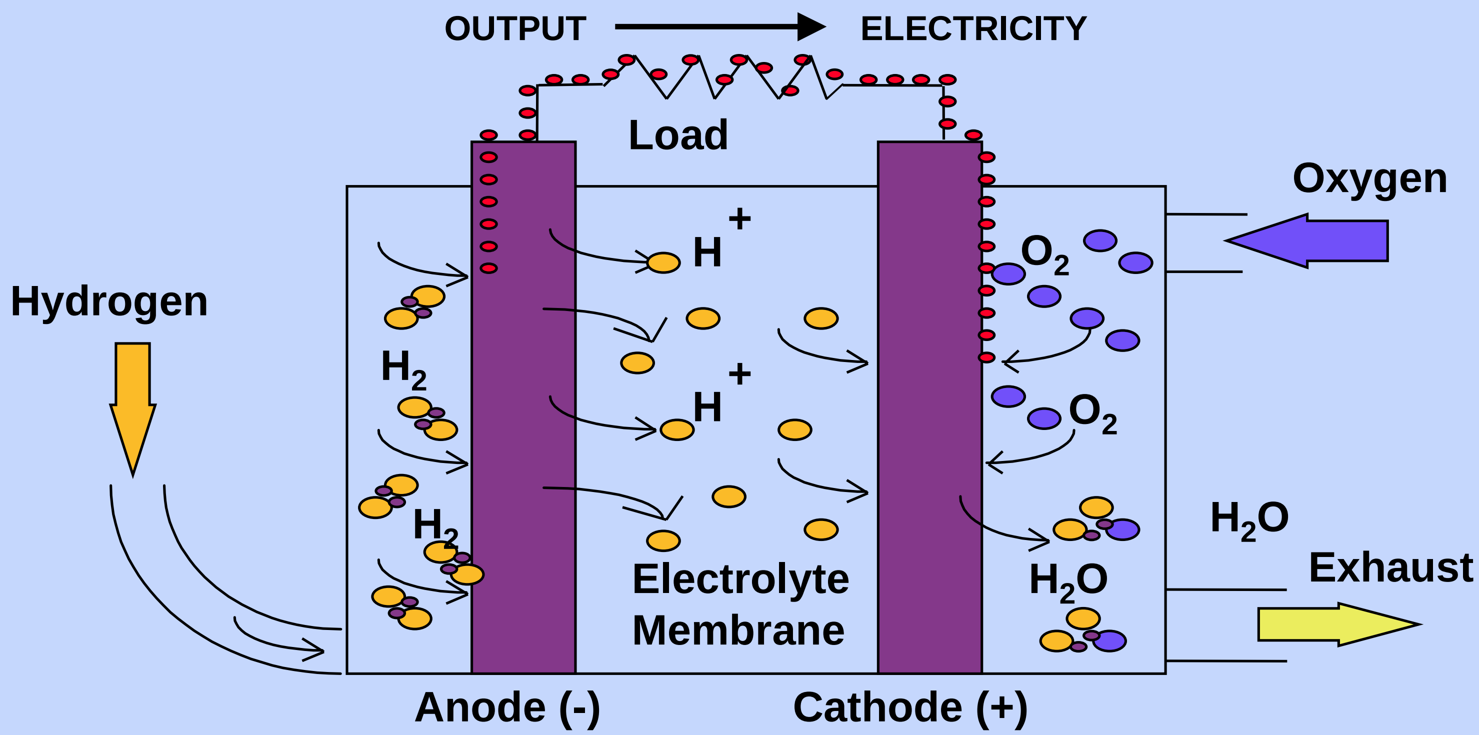
Photovoltaics Efficiency Trends



Ken Zweibel - NREL

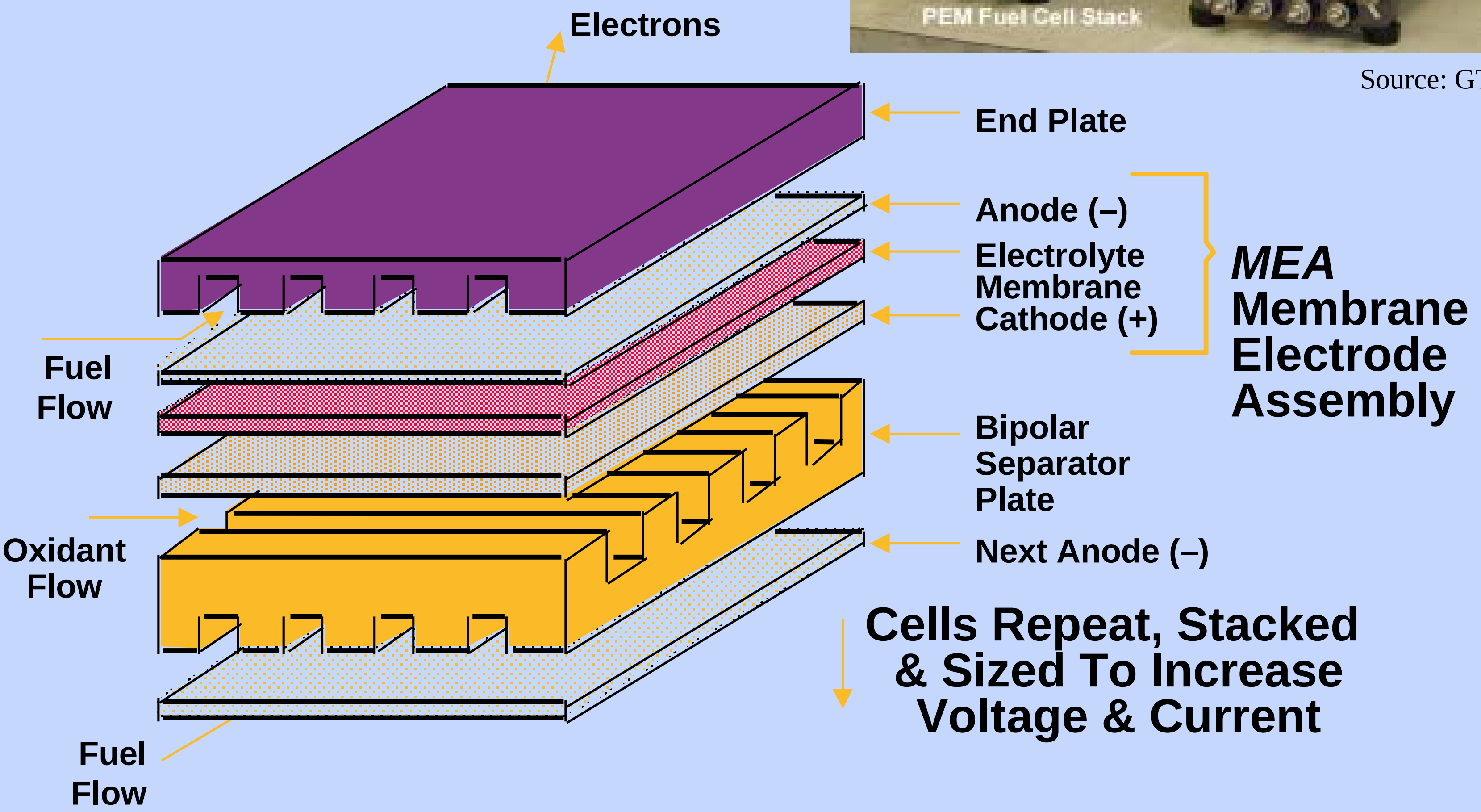
Basic Fuel Cell Operation

Basic Reactions	Combining Hydrogen & Oxygen To Make Electricity & Water
	$H_2 \rightarrow 2H^+ + 2e^-$ $\quad$ $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$



Typical Planar Fuel Cell

Source: GTI

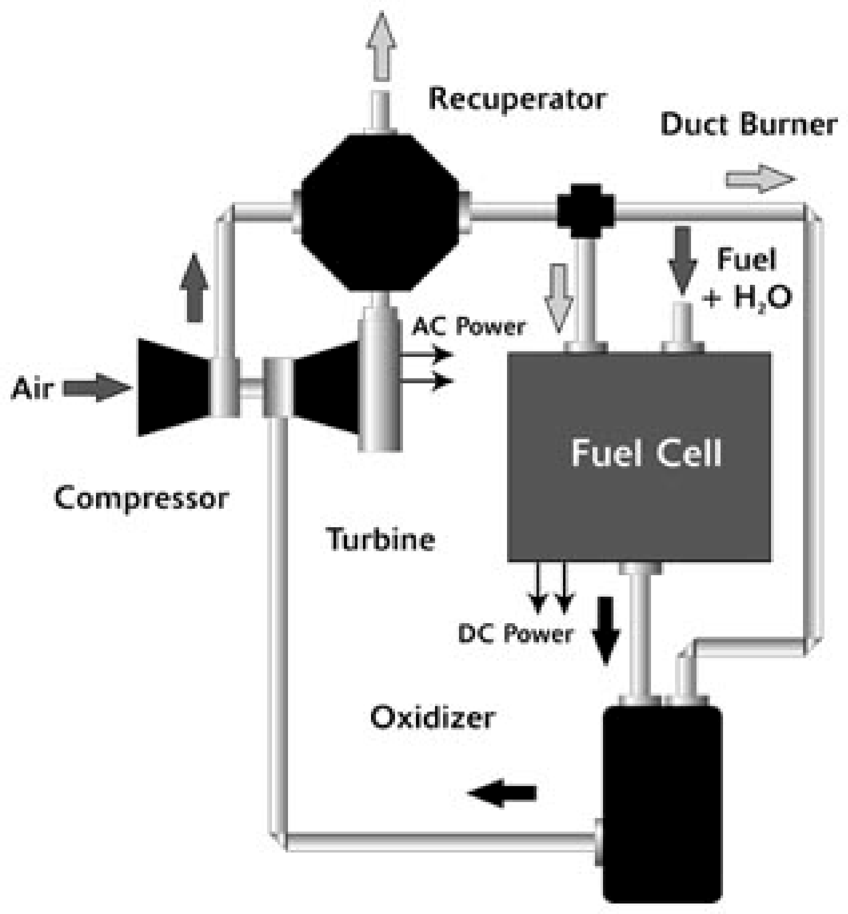


Fuel Cell Attributes

	PEMFC Proton Exchange Membrane	PAFC Phosphoric Acid	MCFC Molten Carbonate	SOFC Solid Oxide
Electrolyte	Sulfonic acid in polymer	Orthophosphoric acid	Lithium and potassium carbonates	Yttrium-stabilized zirconia
Charge Carrier	H^+	H^+	$CO_3^=$	$O^=$
Operating Temperature	175 F Warm Water	390 F Hot Water	1,200 F High-Pressure Steam	1,300 – 2,000 F High-Pressure Steam
Cogeneration Heat	Minimal	Modest	High	High
Efficiency (LHV)	< 40%	35 - 45%	45 – 60%	45 – 60%
Reforming	External	External	Internal or external	Internal or external

Fuel Cell/Gas Turbine Hybrid Systems

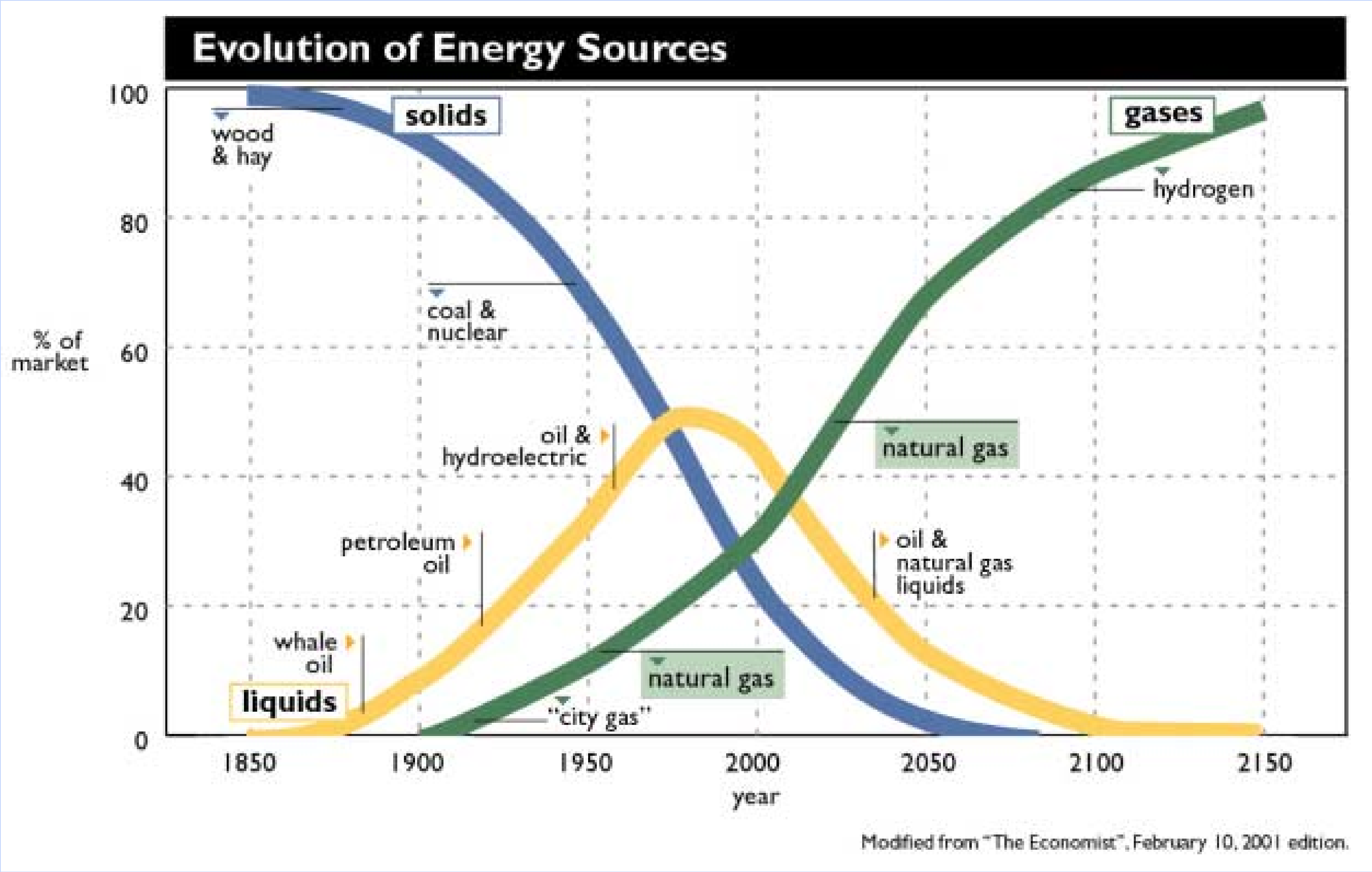
- Goals
  - Synergistic Benefits from Gas Turbines & Fuel Cells
  - 70% (LHV) Electric Efficiency
  - 20MW or Less
  - Commercialization by 2010
- Players
  - S-W/Rolls-Royce
  - S-W/Solar Turbines
  - FCE/Rolls-Royce
  - FCE/Capstone
  - SOFCo/Ingersoll-Rand



Honda FCX V3 Hydrogen Fuel Cell Car

- **Ballard 60kW PEM Fuel Cell**
- **On-board hydrogen storage metal hydride tank (La-Ni5)**
- **Photovoltaic Panels – water electrolysis for hydrogen production**

Long-Term Energy Picture
Historical & Projected Pattern of Use



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Fossil Fuel Transition to Hydrogen

- Coal enjoys large reserves, stable supplies, and low prices – need cleaner, more efficient CO2 sequestration technology
- Oil will maintain its dominant position for fossil fuels – cleaner fuels, more heavy oil upgrading, Hydrogen and power generation in refineries
- Natural gas is fossil fuel “wild card” – large supply with improved options to get to market
  - Convergence with power generation
  - DG cogeneration
  - Fuel cells could hasten transition to Hydrogen

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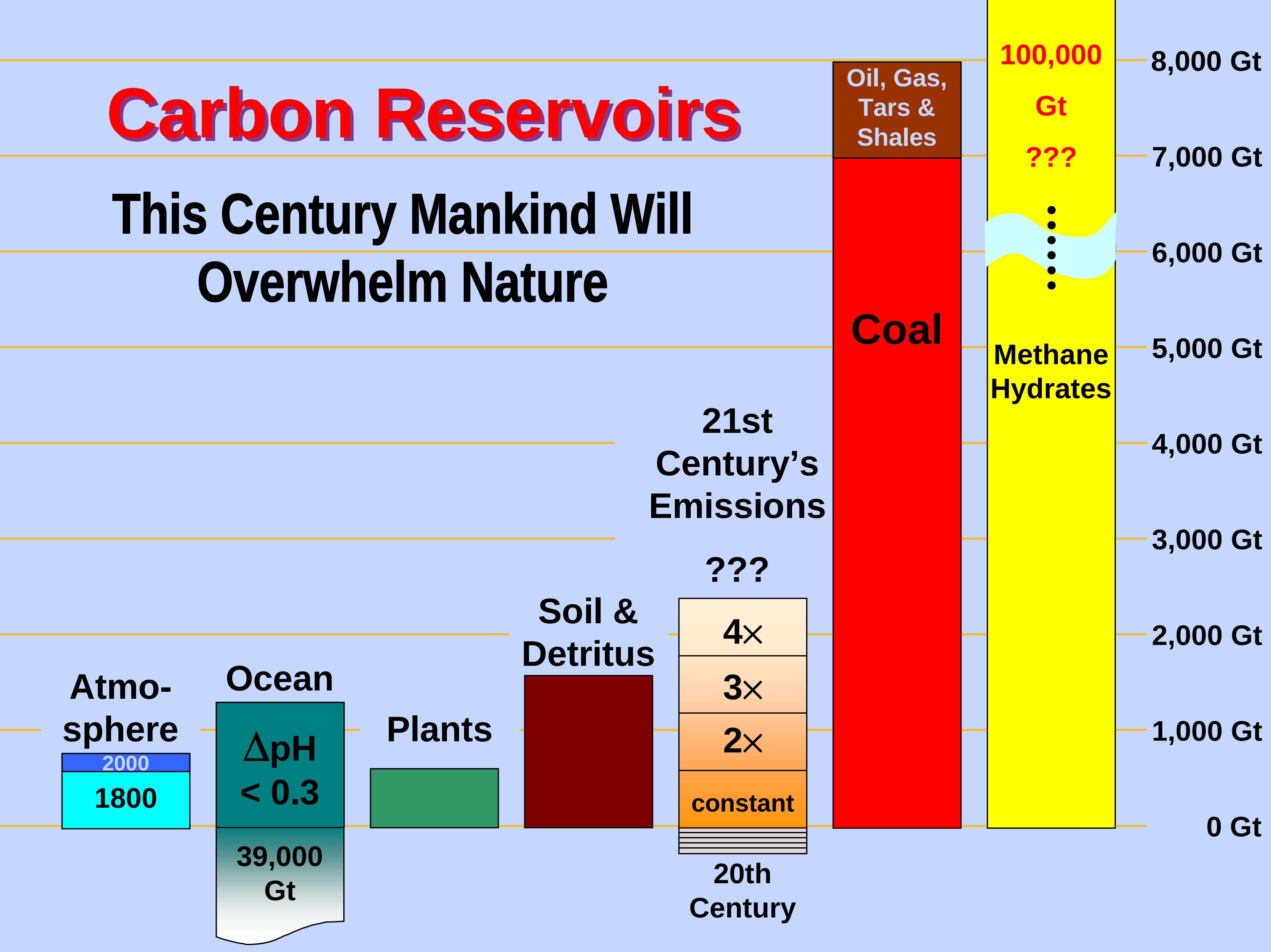
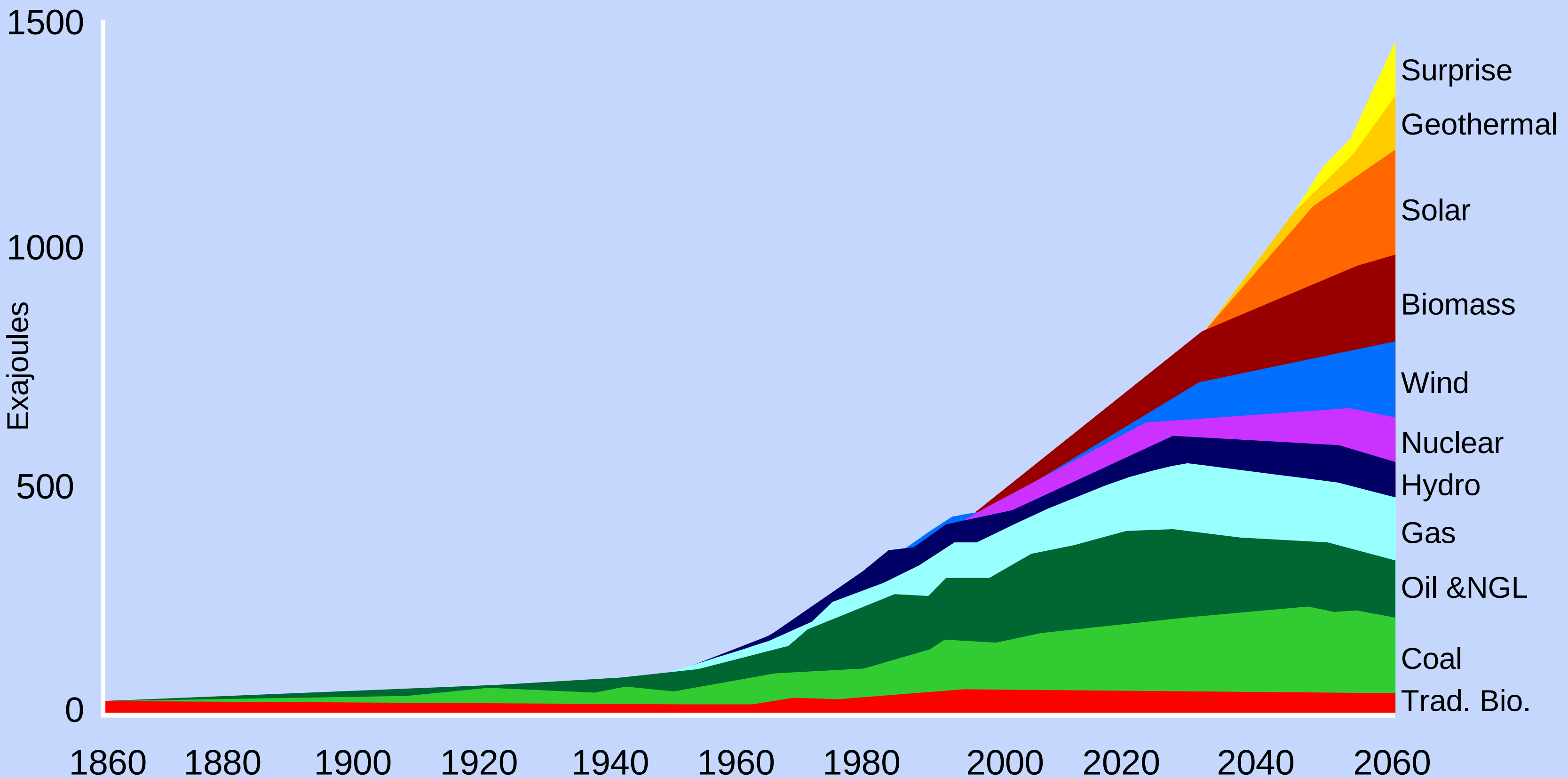
Fossil Fuel Utilization in the 21st Century

- Fossil Fuel Supplies are Adequate to Continue to Provide for World Energy Needs through the 21st Century
- Technology will increasingly make Coal, Oil, and Natural Gas intraconvertable.
- Deregulation, the “dash to gas” (NGCC) & Efficiency Advantages of Cogeneration/ Polygeneration ultimately favors gasification
- Polygeneration – gasification to make synthesis gas for steam/power and syngas chemicals & fuels.



Carbon Reservoirs
This Century Mankind Will Overwhelm Nature
8,000 Gt
7,000 Gt
6,000 Gt
5,000 Gt
4,000 Gt
3,000 Gt
2,000 Gt
1,000 Gt
0 Gt
Atmo-sphere
2000
1800
Ocean
ΔpH < 0.3
39,000 Gt
Plants
Soil & Detritus
21st Century's Emissions
???
4×
3×
2×
constant
20th Century
Oil, Gas, Tars & Shales
Coal
100,000 Gt ???
Methane Hydrates

Shell Sustained Growth Scenario



Sources: 1995; Shell, The Evolution of the World's Energy Systems, 1995